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FOAM-IN-PLACE FORM FITTING HELMET LINERS

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Aerospace Defense Command Liaison Office

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FOREWORD

This report was prepared by the Materials Engineering Branch, Materials Support Division, Air Force Materials Laboratory, under Project No. 7381 "Materials Application," Task No. 738106 "Engineering and Design Data." The work was administered under the direction of the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. Mr S. Allinikov of the AFML, Lt Col W. Morton of the Aerospace Defense Command Liaison Office, Wright-Patterson Air Force Base, Ohio, and Mr J. A. Ziegenhagen of the University of Dayton, Dayton, Ohio, were the Project Engineers on this program.

This report covers work from June 1968 to November 1969. The report was submitted by the authors December 1969.

This technical report has been reviewed and is approved.

Albert Olevitch
ALBERT OLEVITCH
Chief, Materials Engineering Branch
Materials Support Division
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ABSTRACT

The feasibility of a foamed-in-place, form fitting foam helmet liner for Air Force crash or flying helmets has been proven. The work done under this program has demonstrated that high quality polyurethane foam helmet liners may be foamed-in-place directly on the flying crew member's head, producing a perfectly fitting helmet liner with a minimum of time, labor, and inconvenience. Furthermore, these liners may be produced at an extremely modest cost, and a standard government issue helmet may be customized at a fraction of the cost of a commercially available customizing service, and in a fraction of the time.

The work involved two areas of effort. One area centered around developing a suitable foam formulation to produce the foamed-in-place helmet liners. The other was concerned with fabricating a workable mold, which would be worn by the individual being fitted for a custom helmet liner during the foaming process.

A suitable polyurethane foam formulation has been tailored to the specific requirements for the foam-in-place helmet liners prepared under this program. Design and fabrication of a suitable mold in which the helmet liner is foamed has progressed to a point which has definitely demonstrated that the concept of foamed-in-place helmet liners is not only practical but also desirable.

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INTRODUCTION

The pilot's helmet is of considerable importance to the Air Force. It must be worn for long periods of time and hence must be comfortable. During tactical maneuvers the pilot's head is violently bounced about and needs protection against shock. Also the helmet must house earphones. Hence, this article of apparel has advanced from the simple cloth cap used at the outset and the flexible leather skull cap of World War II to the rather sophisticated flight or crash helmet of today which costs about $70.00. Several modifications have been made on the design of the flight helmet since its inception; however, certain deficiencies still exist. Securing a proper fit on each individual's head remains a problem and a loose-fitting, very uncomfortable helmet is often inevitable. This is pointed out in the TAC ROC* which stipulates the need for better fitting helmets among other things. The solution to the poor fit problem is to custom-fit a helmet liner for each individual. Helmets with custom-fit liners are available to some crew members, but only on a limited basis, due to excessive cost and inconvenience of preparing this type of liner.

Lt Col William G. Morton of the Aerospace Defense Command Liaison Office at Wright-Patterson Air Force Base suggested the possibility of using foam chemistry to prepare a form-fitting helmet liner directly on the wearer's head. This could be done at any installation and thus make available custom-fit helmet liners for every helmet wearer. In order to reduce this novel concept to practice, it was necessary to develop and optimize a foam formulation which could be mixed and dispensed without sophisticated equipment and which could be safely applied to a person wearing a suitable mold; and develop a suitable mold to be worn by the individual in which the helmet liner may be foamed. It would be necessary to produce a finished foam helmet liner with physical properties at least equal to those of the standard helmet foam liner now available. The advantage of this system would be the capability of preparing form-fit helmet liners at a very low cost, minimum inconvenience, and last, but not least, minimum logistics. This report discusses the work leading to a successful demonstration of the foam-in-place method of custom fitting the pilots' helmets.

*Required Operational Capability

CURRENT STATE-OF-THE-ART

At present there are two methods of providing a fitted helmet. The standard issue helmet does not provide a really good fit for every pilot. It consists of a polystyrene foam shell placed in the helmet. Strips of foam rubber are inserted in this helmet while it is on the head. By trial and error the locations giving the best fit are determined and these strips of foam rubber are bonded into place. The fit that is thus secured is far from optimum.

To get a true perfect fit a plaster cast is made of the head. This cast is then shipped to a contractor. He then makes a male mold reproduction of the head in this plaster cast. This reproduction of the head is then placed into a mold so spaced as to provide for foaming the helmet liner. Polystyrene beads are introduced into the space and foamed by use of steam or heat. The helmet liner thus foamed will fit perfectly on the pilot's head. This is then shipped to Wright-Patterson AFB for insertion into the helmet. Because the process is so specialized, time consuming, and expensive, this technique is not in wide use. The foam-in-place process discussed herein, requires less than 25 cents worth of chemicals and the liner is fabricated in a matter of minutes.

TARGET REQUIREMENTS OF A FOAMED-IN-PLACE HELMET LINER PROCESS

The helmet liner presently fitted consists of a Styrofoam shell with strips of foam rubber padding located at various points. It is necessary that the foamed-in-place polyurethane foam liner have physical and mechanical properties at least equal to the properties of the Styrofoam shell. At the same time, it must be of approximately the same density as the Styrofoam, and non-toxic to the wearer. It was necessary to keep a number of factors in mind during the screening of the various polyurethane foam-in-place formulations, i.e., (1) it is necessary to produce a good quality foam of the required density with a high degree of uniformity and reproducibility from liner to liner, as well as within each liner; (2) no air bubbles or other voids are to be allowed; (3) the finished foam liners must have cells of uniform size, and no heat fissures or areas of resin densification; (4) the chemicals used to produce the foam must be of low viscosity to facilitate easy handling and pouring; (5) the foam chemicals must be capable of being mixed and poured in the field without the aid of mechanical mixing and dispensing equipment; (6) the reaction time should be reasonably rapid to produce the foam in comparatively short time, but slow enough to allow injection of the chemicals into the mold; (7) the exotherm generated during the reaction must be of low enough temperature to be tolerated by the individual wearing the helmet.

OPTIMIZATION FOAM REACTANTS

This program involved two areas of effort: one area was concerned with the optimization of a suitable foam formulation compatible with the helmet liner mold and capable of being prepared in the field without sophisticated equipment; and development of a suitable mold to contain the foam during the foaming process.

The starting point in the foam optimization effort was a formulation originally developed by the Monsanto Research Corporation (MRC) under a Navy contract to explore various concepts for imparting permanent flotation to life rafts. Under Air Force contract, MRC had demonstrated a packaged formulation wherein the foam could be mixed and generated within this package. This concept is now being further explored by the Air Force Logistics Command as a way of generating foam in the field for cushioning and returning delicate instruments from the field for recalibration.

Due to the requirement for low exotherm temperature, it was decided to select a foam making use of Freon as a blowing agent. Freon-blown formulations generally produce a lower exotherm temperature during reaction than do conventional carbon dioxide-blown foams. The MRC polyurethane foam formulation is shown as follows:

Isocyanate Component:	Mondur MR	45.0 g.
	Freon 11	7.0 g.
	Dibutyl tin diacetate	0.05g.
Polyol Component:	Pluracol TP-440	40.0 g.
	Silicone DC-113	0.6 g.
	Freon 11	10.0 g.
	C-16 catalyst	0.05g.

Mondur MR, the isocyanate component, is a crude form of diphenylmethane diisocyanate. It is produced by Mobay Chemical Company. Freon 11, the blowing agent, is a trade name for trichloromonofluoromethane. It is sold by E. I. duPont de Nemours and Co.

Dibutyl tin diacetate is a catalyst to effect the reaction. The Pluracol TP-440 is the polyol component of the formulation and is the trade name for polyoxpropylene polyol based on trimethylolpropane. It is made by Wyandotte Chemical Company. The Silicone DC-113, a silicone glycol copolymer, is used as a surfactant to act as a nucleating agent for the formation of cells in the foam. It was produced by Dow Corning Corporation. The C-16, a derivative of piperazine, is a catalyst used to control the foam reaction. It also is made by Mobay Chemical Company.

According to the manufacturer, the foam produced using this formulation should have a density of approximately two pounds per cubic foot. The chemicals to make up the isocyanate component are mixed together and stored

separately from the other chemicals mixed together to form the polyol component. This particular system was chosen as a candidate because of the claimed low exotherm generated during the reaction, and by the ease of mixing. The isocyanate component is merely added to the polyol component and the two mixed and stirred for several seconds. Both components are of low viscosity to ease mixing. Both isocyanate and polyol components were supplied by MRC for experimentation. To prepare the foam in the laboratory, equal weights of the two components were poured in a paper cup and stirred with a wooden paddle vigorously until the mixture turned to a dark color. The foam would begin to form several seconds later and the entire foaming operation was completed in about one minute. The foam was first prepared in paper cups in the laboratory. Uncoated paper cups were used. After the foam had cured, it was cut in two parts for inspection. It was discovered that cell size was not uniform and numerous voids were present. Fissures and splits produced by the heat generated were present also. The cell walls of the foam apparently did not cure quickly enough to provide enough strength to contain the Freon blowing agent. A great amount of shrinkage upon curing of the foam was present. This indicated improper and insufficient curing of the foam. The area at the bottom of the cup showed evidence of unreacted foam chemicals. This foam formulation was also tried in an experimental helmet liner, the compounds being mixed together and poured into an opening in the top of the experimental mold, as described elsewhere in this report. The resulting foam helmet liner is shown in Figure 1. As shown by the photograph, the helmet liner produced using this formulation was completely unsatisfactory. In addition to the defects noted above, there were areas of densification where the blowing agent apparently did not properly perform the foaming function.

It was apparent that this particular formulation would not be satisfactory for producing foamed-in-place helmet liners and that the formula would have to be modified to the specific needs of the foamed-in-place helmet liner. The first modification is shown below

Isocyanate Component:	Mondur MR	47.5 g.
	Freon 11	5.25g.
	Dibutyl tin diacetate	0.07g.
Polyol Component:	Pluracol TP 440	40.0 g.
	Silicone DC 113	0.6 g.
	Freon 11	7.5 g.
	C-16 Catalyst	0.07g.

The quantity of Mondur MR was increased over the amount used in the original formulation, as were the two catalysts, in an attempt to produce a more complete reaction. The amount of Freon 11 was reduced, as it was felt that the reaction was too cool to facilitate completion. More foam samples were prepared in paper cups. The quality of the foam produced had improved, but results were still not satisfactory.

The C-16 catalyst seemed to retard the cure in some fashion. This was borne out through experimentation by foaming in paper cups. Better foams were prepared using dibutyl tin diacetate in place of the C-16 catalyst in the polyol component resulting in the following formulation:

Isocyanate Component:	Mondur MR	47.5 g.
	Freon 11	5.25g.
	Dibutyl tin diacetate	0.07g.
Polyol Component:	Pluracol TP 440	40.0 g.
	Silicone DC 113	0.6 g.
	Freon 11	7.5 g.
	Dibutyl tin diacetate	0.035g.

The small quantity of dibutyl tin diacetate had been substituted for the C-16 in the polyol component, whereas everything else remained the same. Foam prepared with this formulation gave much better results. Cure was complete and shrinkage reduced. There were no unreacted areas in the foam samples, however, numerous heat fissures still presented a problem, as shown in Figure 2. The foam reaction was too hot as the Freon apparently expanded so rapidly that it could not be contained by the as yet uncured cell walls. Therefore, another modification was tried in the formula shown below:

Isocyanate Component:	Mondur MR	47.5 g.
	Freon 11	5.25g.
	Dibutyl tin diacetate	0.07g.
Polyol Component:	Pluracol TP 440	40.0 g.
	Freon 11	12.0 g.
	Silicone DC 113	0.6 g.
	Dibutyl tin diacetate	0.06g.

In this formulation the Freon 11 content was increased to cool off the foam, and hopefully to eliminate the heat fissures. The additional blowing agent did indeed prevent fissure formation; however, the test samples did not exhibit proper cure. More catalyst was added to the polyol component to provide proper curing but shelf life problems developed as is next discussed.

SHELF LIFE

During the experimentation with the last formulation cited, it was noted that the shelf life of the two components appeared to be unreasonably short. After a short storage time, the chemicals would not produce adequately cured foam. Figure 3 shows a comparison between two free-foam samples in paper cups. The sample on the left is improperly cured as compared to the properly cured sample on the right. The same amount of starting materials were used for both samples. Note the high degree of shrinkage in the sample on the left. It was first thought the tin diacetate catalyst was unstable in this system, so another catalyst,

stannous octoate (stannous-2-ethylhexoate) was tried. Initially, it was decided to use the same amount of stannous octoate as was determined for the dibutyl tin diacetate. Therefore, the following formula was tried:

Isocyanate Component:	Mondur MR	47.5 g.
	Freon 11	5.25g.
	Stannous Octoate	0.07g.
Polyol Component:	Pluracol TP 440	40.0 g.
	Silicone DC 113	0.6 g.
	Freon 11	12.0 g.
	Stannous Octoate	0.06g.

The foam produced from this formulation was unsatisfactory, primarily due to improper cure. More catalyst was added, which only produced a foam with heat fissures. No matter what quantity of stannous octoate was used, the resulting foam was never as high in quality as that using the dibutyl tin diacetate catalyst.

It was decided to return to the use of only dibutyl tin diacetate for all subsequent foam formula preparations. Since it was suspected that the catalyst in the isocyanate component was reacting with the Mondur MR during storage, all the catalyst was put in the polyol rather than splitting it between the two components. The formula used was as follows:

Isocyanate Component:	Mondur MP	47.5 g.
	Freon 11	5.25g.
Polyol Component:	Pluracol TP 440	40.0 g.
	Silicone DC 113	0.6 g.
	Freon 11	12.0 g.
	Dibutyl tin diacetate	0.52g.

This formulation produced excellent foam in all respects. Free-foam experiments using this formulation produced a foam of good uniform cell size, with no fissures, voids, areas of densification, or other flaws. The foam cured rapidly with minimum shrinkage. Moreover, reproducibility from batch to batch was good, provided the chemicals were handled properly. The density of the free-foamed polyurethane foam, in the paper cups, using this formulation is about 2.5 pounds per cubic foot, which meets the requirements for the helmet liner foam. The density may be altered by varying the amount of Freon 11 used in the formulation. The greater the amount of Freon used, the lower would be the resulting density of the foam produced.

Furthermore, the two components were stored in their respective bottles under nitrogen to further promote shelf life. Excellent stability was obtained after several weeks and even months of testing.

During the course of this work Dow Corning could no longer supply

the DC 113 surfactant, but rather offered their DC 193 with the assurance that it would perform the same as the DC 113. Our experimentation indicated that the DC 193 performs identically to the DC 113 previously supplied.

POST CURE

The effect of humidity on dimensional stability of the helmet liner foam is related to the degree of cure to which the foamed material has been subjected. Samples of foam representing undercure, normal room temperature cure, and oven post cure at 160°F for 90 minutes, were placed in a 120°F temperature and 100% RH humidity cabinet. Measurements taken and visual observation of the samples made after 10 days and then six weeks exposure showed the greatest changes had taken place in the undercured and room temperature cured foams each time. These foams had warped from the original flat configuration and also showed a 6% change in thickness for the undercured sample, and 3% change for the room cured piece after 10 days in the humidity chamber. Changes in foam thickness were 14% and 6% for the undercured and room cured samples respectively, after six weeks. The oven cured foam showed no change in 10 days, and a 1.5% increase in thickness after six weeks. This sample had not warped from its original flat shape.

RELEASE AGENTS

During development of the mold, various release agents were tried to facilitate removal of the finished foam liner from the mold. However, in every case but one, the release agent applied to the mold surfaces which came in contact with the foam caused collapse of the foam during the foaming reaction. Release agents tried included a paste, Frekote 33 (a plastic mold release agent which was aerosol sprayable), paste and liquid floor wax, and a silicone liquid. The most successful release agent tried, so far, was Dow Corning #92-009, a silicone rubber dispersion. This proved quite satisfactory as a release agent since it did not cause collapse of the foam during the foaming reaction. Another advantage of this particular release agent was that it was reusable, i.e., effective for many helmet liner pours without having to apply a new coating after every use.

HELMET MOLDS

The other area of effort was concerned with the designing and fabricating of a suitable helmet liner mold. This device was to be placed on the head of the pilot or other crew member and would make it possible to safely foam-in-place a form-fit liner. It was necessary that safety be stressed, as care had to be taken to insure that foam chemicals would not touch the skin or hair of the individual's head during the pouring and curing processes.

For the first attempt, a plain helmet shell was used as a mold. A hole was bored in the top of the shell through which the mixed chemicals

were poured. A makeshift foam rubber strip dam was inserted between the individual's head and the inside of the helmet shell, in an attempt to contain the foam. The individual wore a bathing cap to prevent the reactants from touching his skin and hair during the foaming operation. Results were very poor in that leakage was a major problem. This was due to the poor efficiency of the foam rubber dam. In addition, the quality of the foam produced was poor.

The formulation as supplied by a contractor was used for this first attempt, and the resultant liner is shown in Figure 1 as previously mentioned. Besides reflecting the shortcomings of this formulation as noted elsewhere in this report, it was also apparent that more venting was required in the upper mold shell to allow the gases generated during the reaction to escape. This would have lessened the problem of voids and uneven density areas in the foam liner.

In the second attempt, more care was taken in the preparation of a suitable mold, one at least that would not have as great a tendency to leak. The resultant helmet liner mold is shown in Figure 4. As can be seen in the photograph, the mold was fabricated in two parts. The upper half consisted of the upper part of a standard helmet shell, whereas the lower half was made of rubber latex shaped to fit a person's head. The individual continued to wear a bathing cap to keep the foam chemicals off of his hair and skin. The two halves of the mold were fastened together at four points with a nut and bolt. This design proved to be much more workable, as leakage was not nearly as much of a problem as it was before. More holes were drilled in the upper shell of the mold to release the generated gases. Tests of this mold were made using a plaster reproduction of the head.

Although an improvement on the initial design, this mold still had certain drawbacks. The leakage although greatly reduced, was still present, and the nut and bolt fastening arrangement was inconvenient. An insufficient number of holes was bored in the top shell resulting in inadequate venting. A third redesign produced the helmet liner mold shown in Figure 5. This mold was an improvement over the previous design in that it featured a built in, tightly fitting swimmer's cap, which was incorporated into the lower mold half, also made from latex rubber. This eliminated any possibility of leakage between the individual's head and the mold itself. The upper shell was joined to the lower flexible member by four trunk latches, which was much more convenient for assembly and disassembly. More holes were drilled in the upper mold shell, which further aided venting of the expelled gases, and the excess foam generated during the reaction.

A suitable formulation had been developed by this time; however, certain problems still had to be overcome. A suitable release agent still had to be found, as it proved very difficult to remove the foam liner from the mold halves, especially if enough time had elapsed to allow the foamed liner to cure in the mold.

Venting remained a problem, as there were still voids in the foam, especially in the surface of the liner next to the inside of the upper mold shell. Densification of the foam occurred especially in an area around the base of the lower mold half. A typical area of densification is shown in Figure 6, showing a section of a foamed-in-place helmet liner. The densification was apparently caused by comparatively large amounts of foam chemicals confined in a restricted area before having a chance to begin to react and generate foam. It was finally solved by altering the timing of the pouring. It was found that the densification could be eliminated by allowing the chemicals to begin to react in the mixing cup several seconds before pouring into the mold. After the chemicals were mixed, it was found necessary to wait until the mixture showed evidence of the formation of gas bubbles before pouring the contents rapidly into the mold. The final mold design evolved from this work is shown in Figure 7. It consists of the following:

a. Protective rubber cap approximately 1/4" thick. The cap fits snugly over the crew member's head, and serves as an insulator from the 130°F heat developed during the exothermic foam reaction. It also provides the space required for a flexible lining material to be added later to the foam helmet liner.

b. Semi-rigid rubber coated lower mold half, made of the same material as the previously made lower mold halves, which fits directly over the rubber cap. This portion of the mold is fitted with a chin strap which helps to retain the mold on the wearer's head in the same position that a standard helmet would be worn.

c. Rigid fiberglass upper mold half, which fits directly over the lower mold half. The helmet liner is foamed in the space contained between the upper and lower mold halves. The inside surfaces of the two mold halves are coated with the release agent. The upper half of the mold also has an apron to catch the excess foam which is discharged through the vent holes during the foaming operation. There are three larger holes in the top of the upper mold half through which the mixed chemicals are poured prior to foaming. There are three different molds to accommodate the various head sizes. The mold design shown in Figure 7 has proven adequate to successfully apply this technique to about 30 to 40 different pilot's heads. However, for adoption into the inventory, it is felt that a Teflon lined metal mold would be preferred. At present the foam is still somewhat difficult to remove from the mold.

DESCRIPTION OF THE HELMET LINER FOAMING PROCESS

The rubber spacer cap is first fitted on the head of the individual to be fitted with a liner as shown in Figure 8. The spacer cap provides room for the padding and leather covering that will be added to the inside of the liner when finished. The top part of the lower half of the mold is pliable to insure a perfect fit on the individual's head. When fitting the lower mold half on the person's head, care must be taken to insure

that the trapped air inside is squeezed out so that the mold is in direct contact with the rubber spacer cap. Figure 9 shows the lower half fitted. The upper mold half is then fitted directly over the lower mold half and latched in place. This is shown in Figure 10. As soon as the mold is fitted and adjusted to the individual's head, the two parts of the foam formulation are mixed in a paper cup or other suitable disposable container. For field use, the chemicals will be packaged in kits. The kit will contain enough chemicals to produce just one foam helmet liner. Only about five ounces of the mixture are required to make one helmet liner. Certain safety precautions should be taken as the direct skin contact of chemicals and/or breathing of their vapors may be toxic. Mondur MR, a trade name for diphenylmethane diisocyanate, and the Freon 11 which is another name for fluorotrichloromethane, are both potentially toxic, physiologically. The most toxic component of the formulation is the Mondur MR. It is a potent skin and respiratory tract sensitizer. Therefore, care should be taken not to allow the skin to come into contact with the Mondur MR, nor should the vapors produced during the foam reaction be inhaled to any extent. The other toxic chemical employed in the formulation is the Freon 11, and its vapors are also considered toxic. In view of the above considerations, and in addition to the precautions mentioned above, foaming operations should be carried out only under adequate ventilation, such as under a fume hood.*

The two-part formulation is mixed until the chemicals turn to a dark brown shade as in Figure 11. The stirring is then stopped. Shortly afterwards, small bubbles will start to form in the mixture. When it begins to show a frothy appearance on the surface as noted in Figure 12 the mixture is quickly poured into the mold through one or more of the holes in the top. This is shown in Figure 13. The mold is rotated slightly to insure an even distribution of the chemical while it is still liquid. This should eliminate any voids or pockets in the finished helmet liner. Any excess foam will be expelled through the vent holes shown in Figure 14 and it should be wiped away while still in the semi-liquid state. There is a point during the initial curing stage where the excess foam may be peeled off quite easily using paper towels. This is shown in Figure 15. This occurs about a minute after the excess foam is expelled through the vent holes. The heat generated during the foaming reaction is not uncomfortable to the wearer of the mold. The temperature has been measured in the range from about 120 degrees to 130 degrees Fahrenheit at the surface of the foam, which is not excessive. The pressure against the individual's head generated by the expanding foam is also very mild, and barely noticeable.

The mold may be removed from the head after about one-half minute after foaming stops. After several minutes, the helmet liner mold is separated to remove the liner. One must be careful not to remove the foamed liner from the mold too quickly after foaming. The surface of the foam will tend to adhere to the mold if an attempt is made to remove the liner too soon. On the other hand, it will be very difficult to remove the liner if it is allowed to remain in the mold for too long a time.

*The Air Surgeon has reviewed this procedure and noted the hazards involved and the precautions that must be taken if this process is adopted in the field. See Page 14 for further comments.

Generally, the liner may be removed from the mold after approximately 3-5 minutes have elapsed from the time foaming action has stopped. During removal from the mold, the foam liner will undoubtedly be pulled out of shape slightly, as it will not yet be fully cured. Therefore, immediately after removal from the mold, the wearer should again don the rubber spacing cap and firmly fit the newly foamed liner to his head. Figure 16 depicts this step. This will restore the original perfect fit of the foam helmet liner. The liner is then carefully removed and set aside to cure. Curing is usually accomplished over night.

It should be noted, however, that the foam is still not normally completely cured at this time. For example, it has been found through humidity chamber tests that excessive moisture has an adverse effect on the polyurethane foam which has been cured only at room temperature. Therefore, a post cure step to be carried out after the liner has been room temperature cured over night is recommended. It is suggested that the liner be post cured in an oven at 160°F for 90 minutes.

Before inserting the liner in the helmet shell, the liner is cut in half, its convex surfaces smoothed and its concave surface lined with a thin cushioning material and leather. These steps are shown in Figure 17. The customizing of the helmet will be completed using the kit which is a part of the foam form-fitting liner package. A special edge lining will be installed, along with foam ear cushions which will contain the ear-phones. The foam helmet liner may also be grooved as a provision for a built-in ventilation system.

QUALITY ASSURANCE

In order to insure that the foamed-in-place helmet liner will be satisfactory and will have the desired properties, it is necessary to carefully inspect the finished cured bare helmet liner before attempting to incorporate it into the helmet.

In the laboratory, to check for cell size and uniformity, hard spots, fissures, voids, and any other defects, the samples were dissected to obtain typical cross-sections of the foam for close inspection. In the field, a nondestructive method of inspection consists of simply holding the foamed helmet liner up to a relatively strong light source. Being rather thin in cross-section, the liner is somewhat translucent, and such defects are quite noticeable. To be acceptable, the foam liner should show good uniform cell structure throughout, without voids, heat fissures or areas of densification. The density of the foam should be approximately 2.5 pounds per cubic foot.

To get a really accurate and reliable indication of the quality of the finished foam, an actual helmet liner should be prepared. A free-foam sample in a cup cannot be relied upon to give an accurate indication of the quality of foam that can be expected when the actual helmet liner is prepared.

COMPARISON BETWEEN THE STANDARD AIR FORCE ISSUE HELMET AND THE CUSTOM FIT HELMET

Figure 18 shows the standard Air Force issue helmet (left), next to the customized form-fitting helmet (right). Figure 19 shows the standard Air Force issue helmet disassembled, and Figure 20 shows the customized helmet, also disassembled.

The standard issue helmet contains a partial filler liner, produced from Styrofoam, plus additional spacers of sponge rubber and padding to create the best possible fit. However, it has been shown that this fit is still not completely adequate, as the helmet still does not fit very snugly. It could swivel on the head or easily slip over the eyes.

The helmet containing the form-fitting liner and edge lining from the customizing kit will alleviate any problems a flyer may have concerning a loose fitting helmet. There is little chance of a helmet shift on a person's head when it fits like a glove. The foamed-in-place foam lined helmet will also be about two ounces lower in weight than the standard Air Force issue helmet. The customized helmet will be far simpler in construction. As shown in the photographs, there are far fewer parts than in the standard issue helmet.

MATERIALS AND SUPPLIERS

Chemicals used for foam formulations:

	Material	Supplier
Isocyanate Component	Mondur MR	Mobay Chemical Co.
	Freon 11	E.I.duPont de Nemours
Polyol Component	Pluracol TP 440	Wyandotte Chemical Co.
	Silicone DC 113	Dow Corning Corp.
	DC 193	Dow Corning Corp.
	Dibutyl tin diacetate	Matheson, Coleman & Bell Chemical Co.
	C-16 Catalyst	Mobay Chemical Co.
Release Agent	#92-009 Silicone rubber elastomer dispersion coating (white)	Dow Corning Corp.

SPECIFIC GRAVITY MEASUREMENTS

These measurements for the various foam samples were obtained in a very simple manner. A piece of the foam in question was weighed dry. A

beaker was then filled with water, care being taken to insure that the beaker was completely filled. The beaker was placed in a pan to catch any displaced water. The piece of foam was then immersed completely in the water, and the displaced water was caught by the pan. The displaced water was poured into a graduated cylinder and its volume recorded.

The following formula was then applied. Weights were measured in grams and volumes in cubic centimeters.

Density in pounds/cubic foot =

$$\frac{\text{sample weight in grams}}{\text{volume of displaced water}} \times 62.45 \ \frac{cm^3 \ lbs}{g. \ ft^3} = \text{density in pounds/cu ft}$$

WEIGHING CHEMICALS AND OTHER MEASUREMENTS

A triple beam balance was used for weighing all of the chemicals used for the tests, with the exception of the dibutyl tin diacetate and the C-16 catalysts. Since such samples of these chemicals were necessarily very small, an analytical chain-o-matic type balance was required for these measurements.

The exotherm temperature of the foam in the helmet liner foaming experiments was measured with a Lewis Model #78P019 Pyrometer-Potentiometer, utilizing an iron-constantan thermocouple. The thermocouple wire was taped in contact with the plaster dummy head under the bathing cap, in order that it would come in close proximity to the foam during the foaming operation. The temperature was constantly monitored during the reaction, and was approximately 120-130°F.

SUMMARY AND CONCLUSIONS

This program has proven the feasibility of producing a foamed-in-place polyurethane foam liner which is then incorporated into the standard Air Force flying or crash helmet. By means of a special mold and chemicals mixed on the spot, it is possible to prepare a custom-fit helmet liner directly on the pilot or crew member's head.

This program involved two areas of effort: optimization of a foam formulation to produce a foam with the required properties and characteristics; and development of a suitable prototype helmet mold configuration in which the liners could be foamed.

The foam developed by Monsanto Research Corporation of Dayton, Ohio for their bag-in-a-bag packaging concept was evaluated for helmet liner use. However, this foam proved inadequate for several reasons, and an optimized formulation was prepared in the Air Force Materials Laboratory specifically tailored for use in preparing helmet liners.

The other area of this program was concerned with designing and fabricating a suitable mold which would at least be adequate for preparing a limited number of foam helmet liners to prove practicality of the technique. After several attempts, a suitable helmet liner mold was produced, which has proven very successful. Three sizes of the mold were prepared, to accommodate the various head sizes encountered.

The helmet liner mold type prepared in this program is experimental and requires improvements before being produced in quantity for Air Force wide use. It is anticipated that a kit will be provided to foam the helmet liner and to incorporate the finished foamed liner into the government issue standard helmet shell. In addition to the foam chemicals, the kit will contain the earphone pads, leather and foam rubber stripping to complete the customizing process. The kit will include the required chemicals in such quantity as to provide foam for only one helmet. The customized helmet containing the foamed-in-place liner will be extremely simple in construction, as compared to the standard government issue helmet. It will be possible to customize a standard issue helmet on any installation at squadron level and at very low cost. This is in direct contrast to the very expensive and impractical-to-produce, custom-fit helmets available on a very limited basis today.

The Life Support System Project Office is conducting an Operational, Test and Engineering (OT&E) effort to thoroughly evaluate the usefulness and practicality of this new process for in the field application. Several Air Force operational squadrons will participate in tests to apply this process for making custom fit helmet liners. Should the results be positive indicating eventual adoption by the Air Force, the problem of providing instructions and equipment such as vapor collecting devices to insure no hazards to personnel will be resolved.

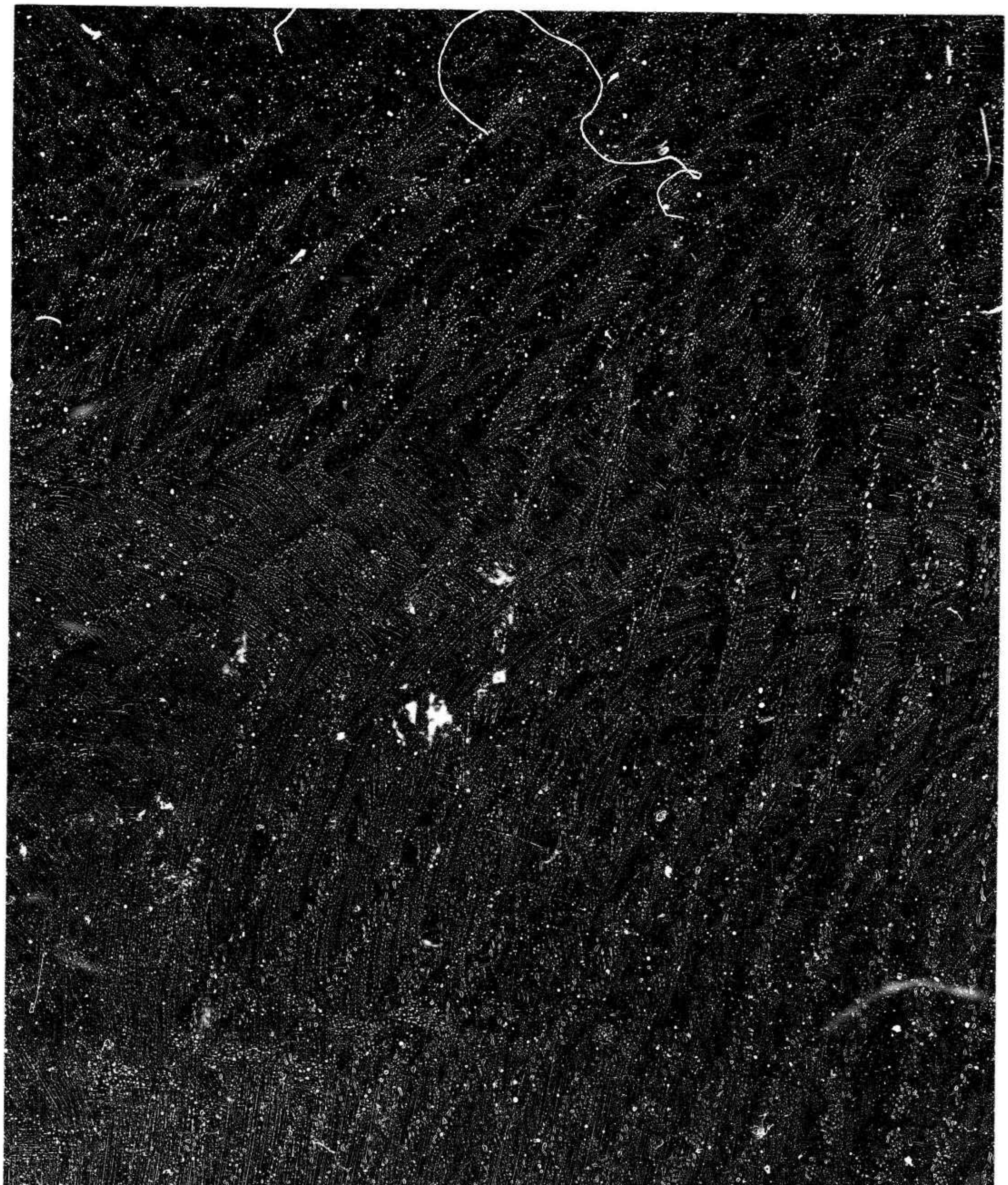

FIGURE 1. Initial Helmet Liner

FIGURE 2. Heat Fissures

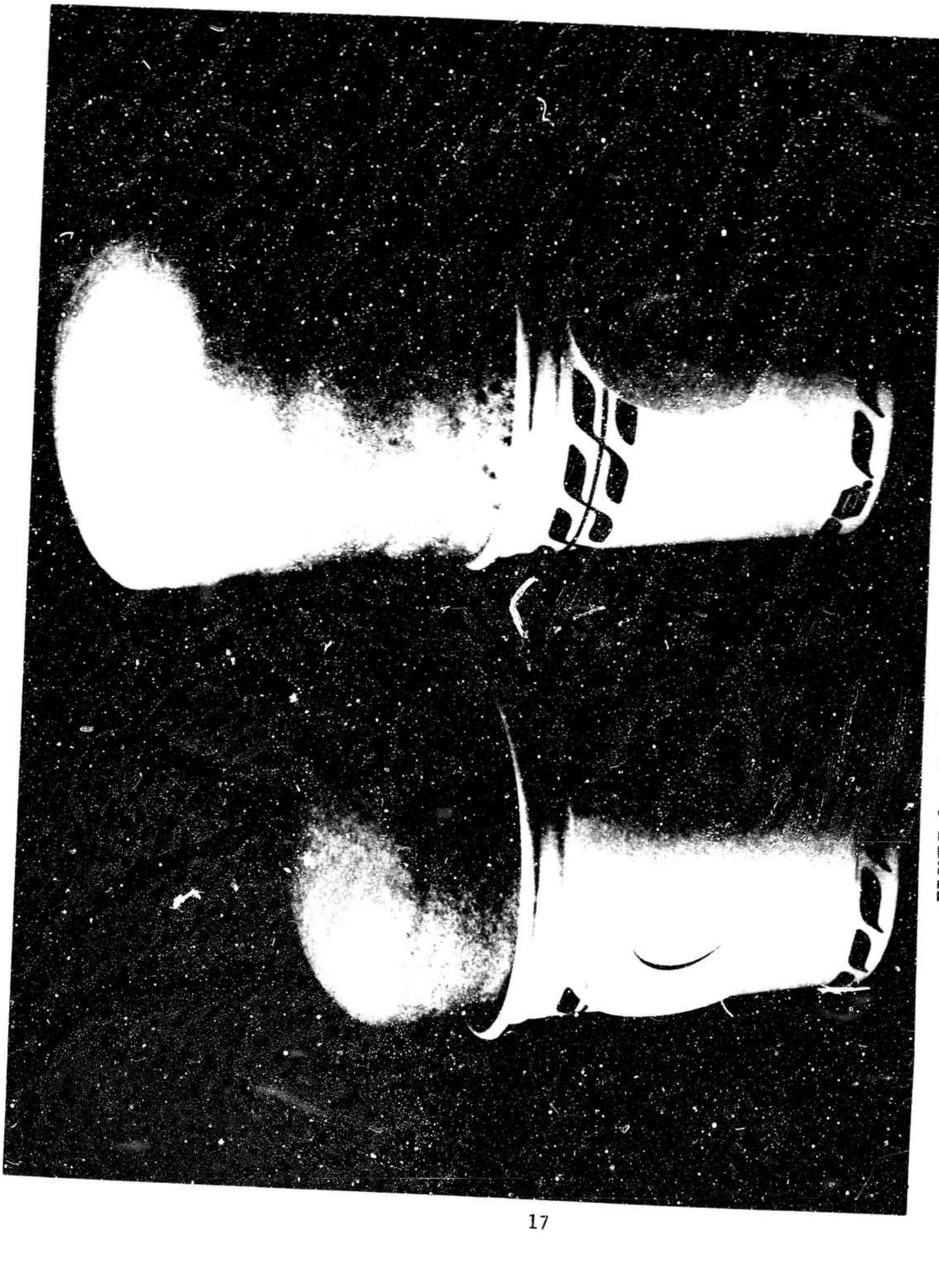

FIGURE 3. Cured vs. Uncured Specimens

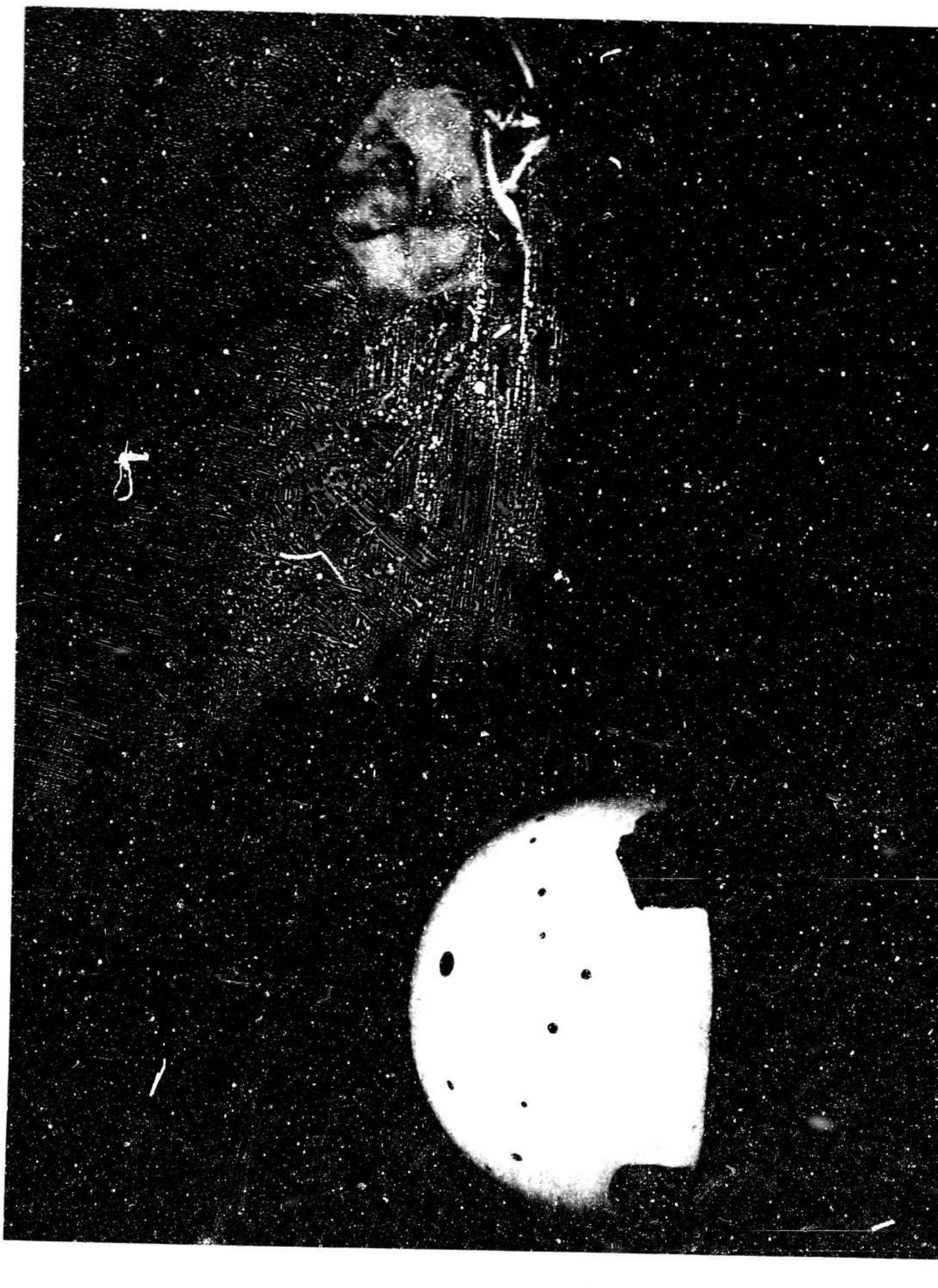

FIGURE 4. First Helmet Liner Mold Design

FIGURE 5. Second Helmet Liner Mold Design

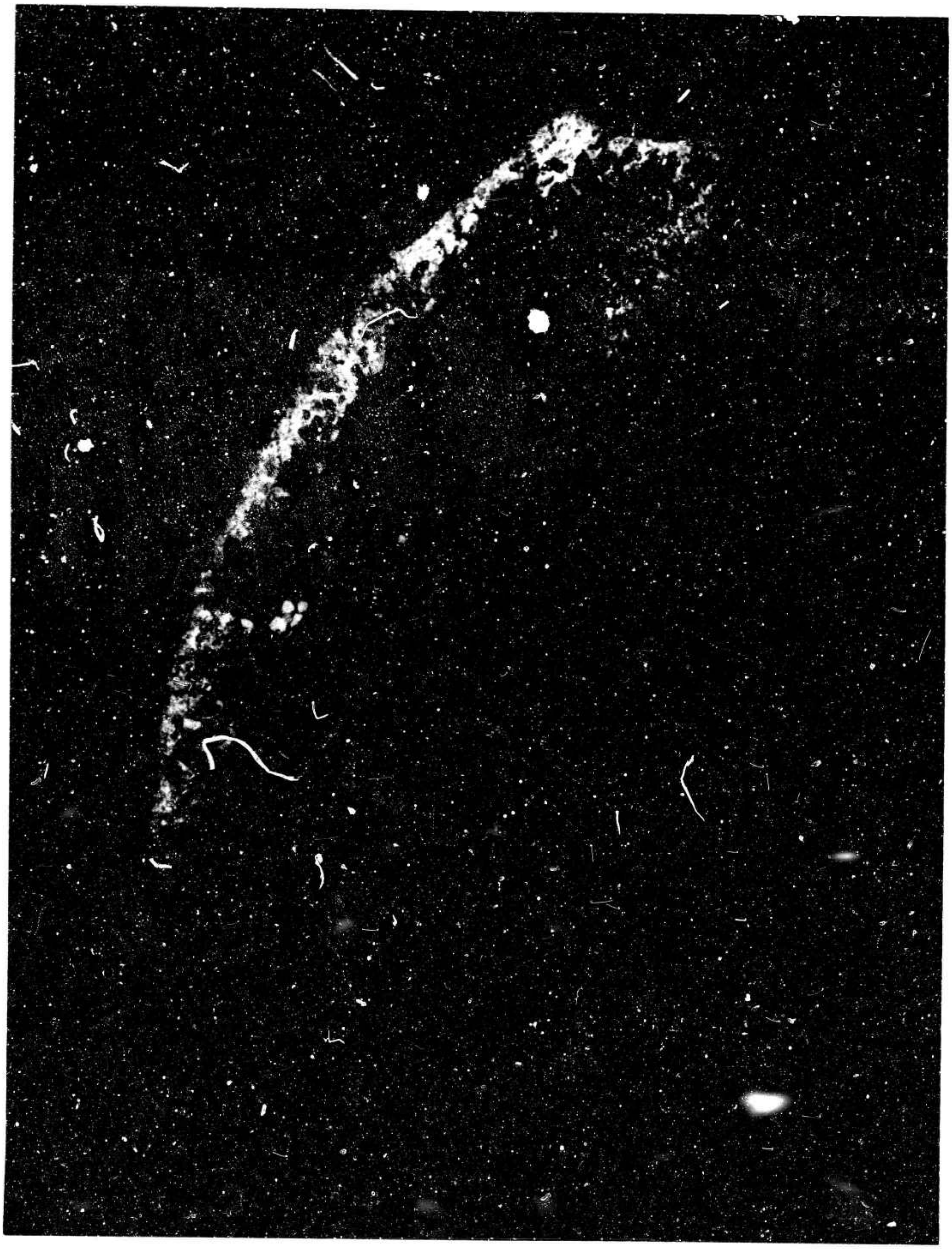

FIGURE 6. Area of Densification

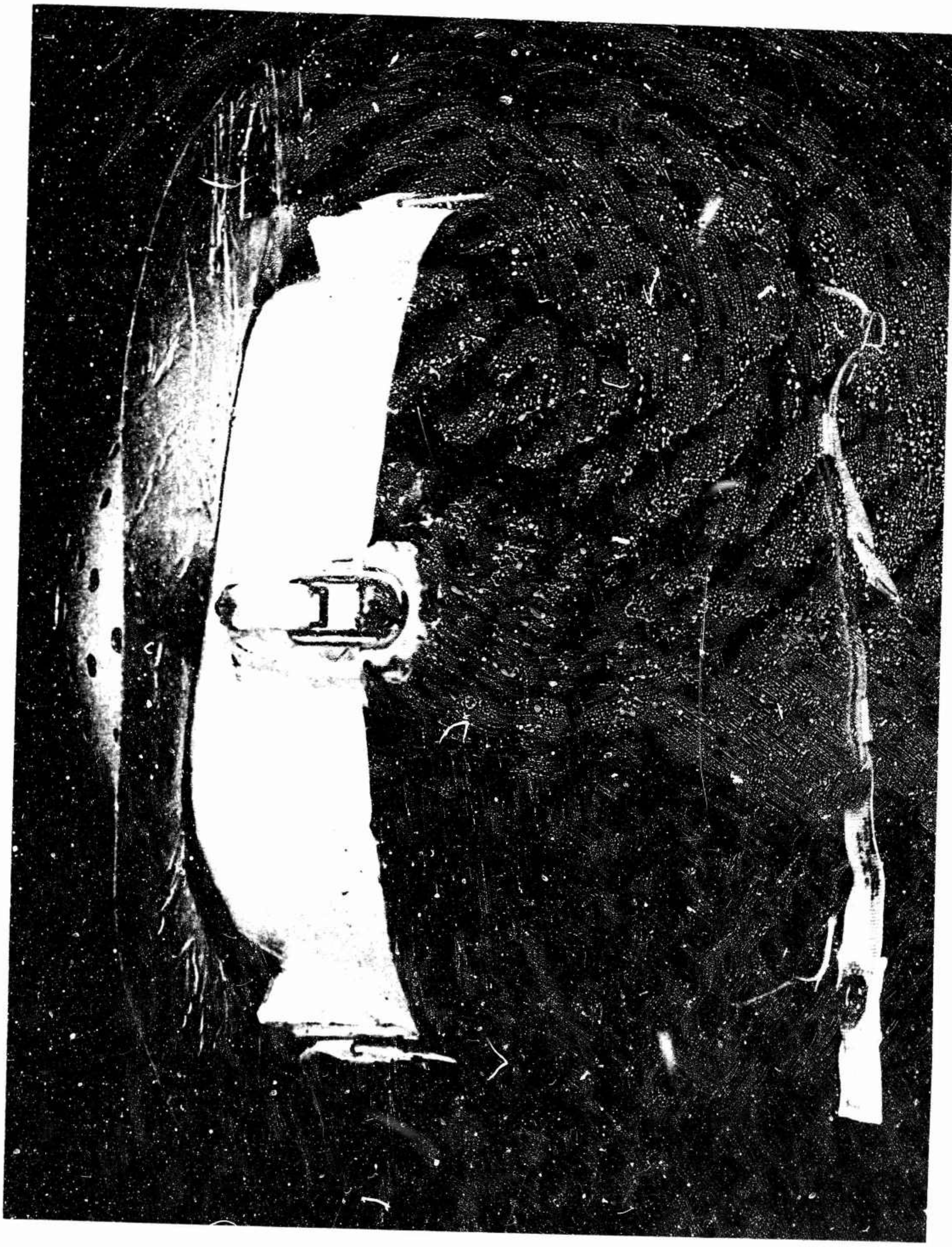

FIGURE 7. Final Helmet Liner Mold Design (Present Design)

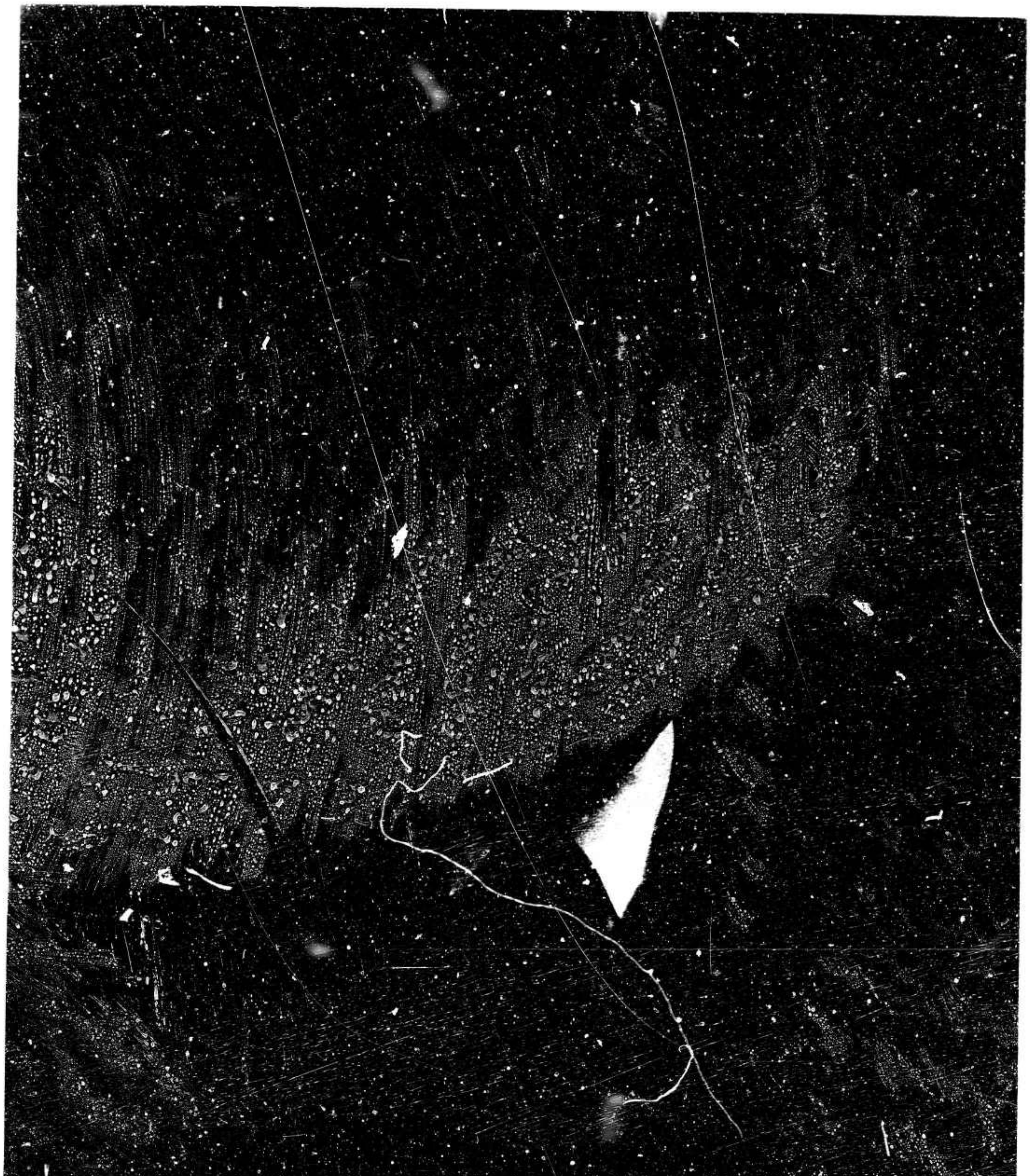

FIGURE 8. Fitting of Spacer Cap

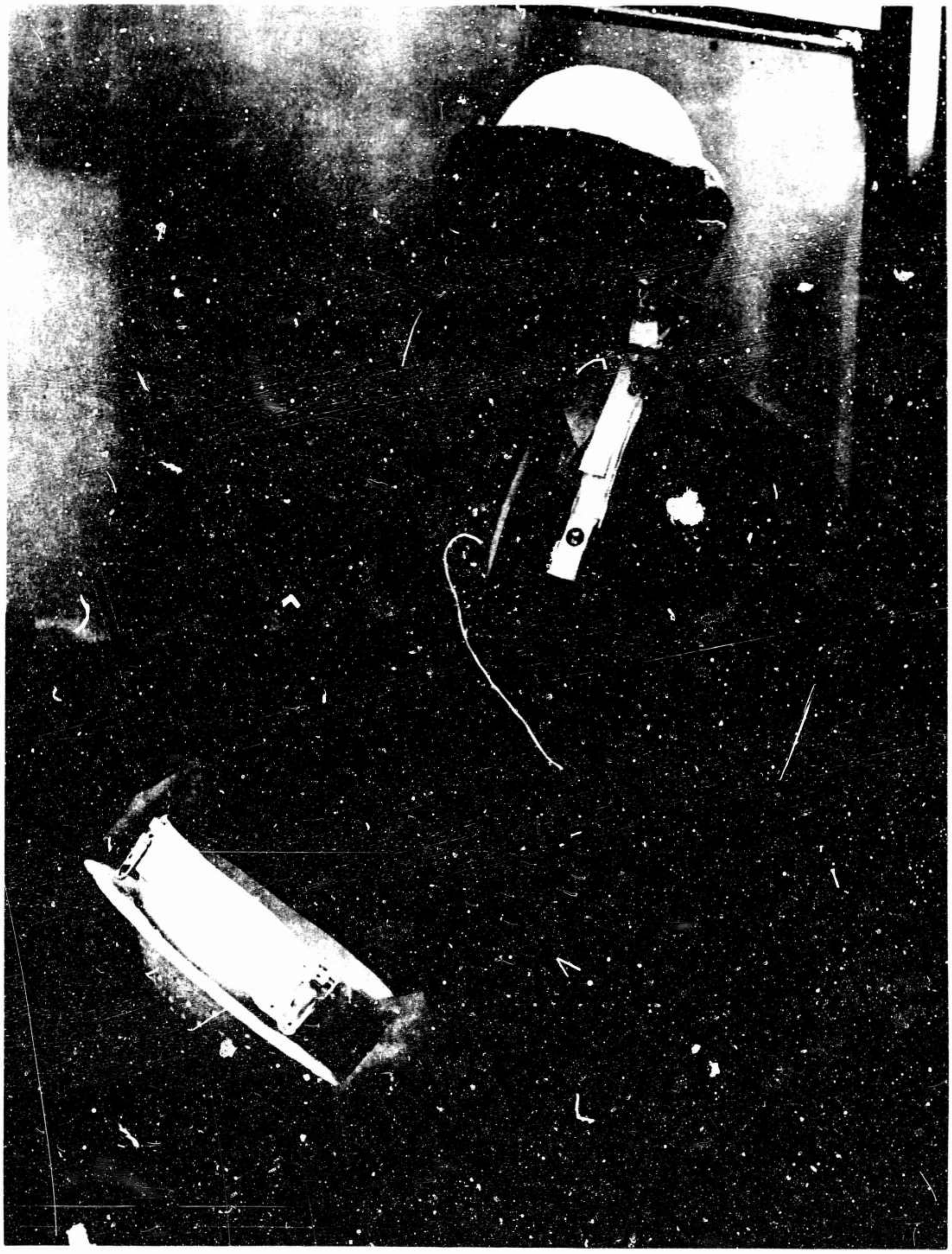

FIGURE 9. Fitting of Lower Mold Half

FIGURE 10. Fitting of Upper Mold Half

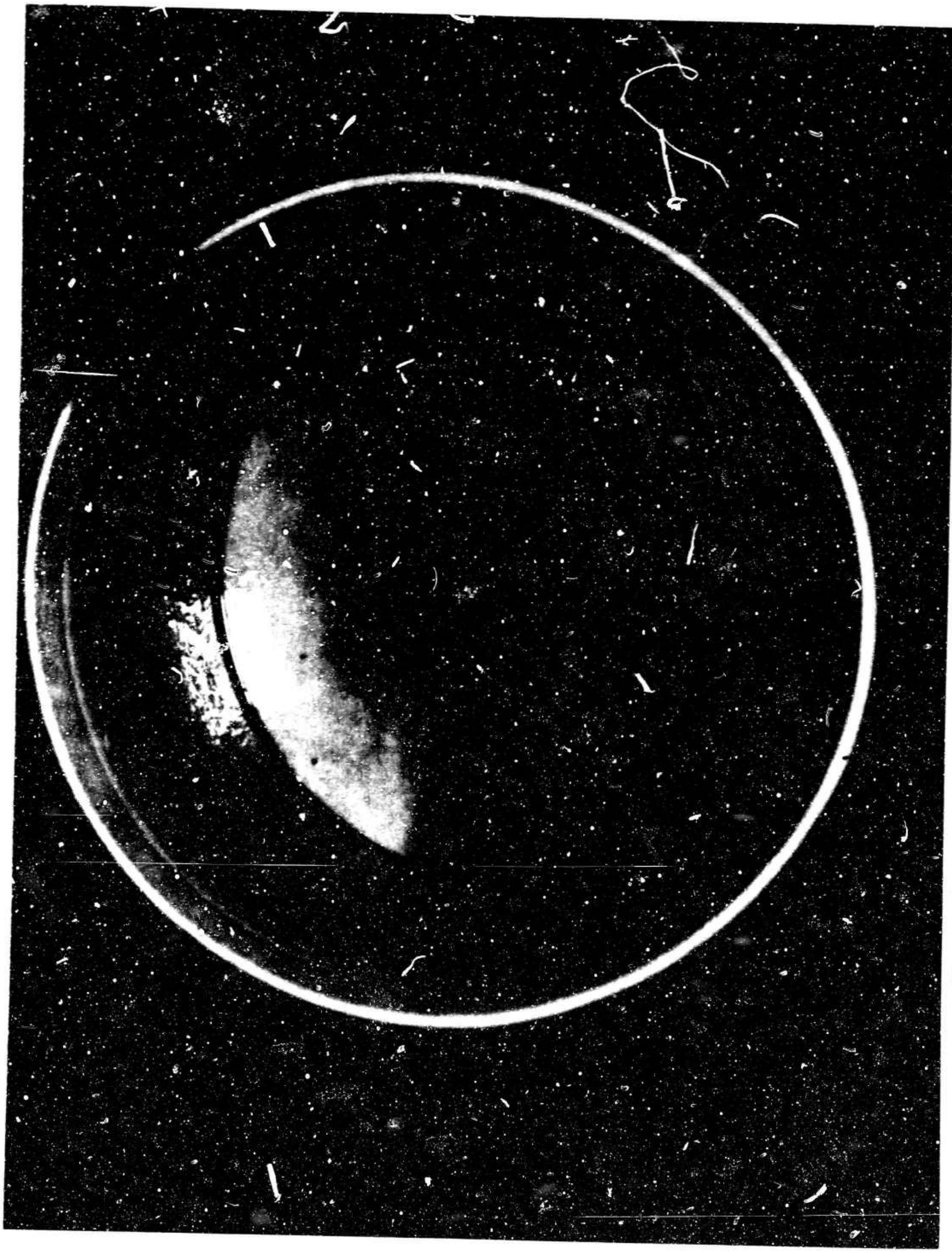

FIGURE 11. Mixing Foam - End Point of Stirring Indicated by Dark Brown Coloration

FIGURE 12. Mixing Foam - Start of Frothing

FIGURE 13. Pouring the Foam

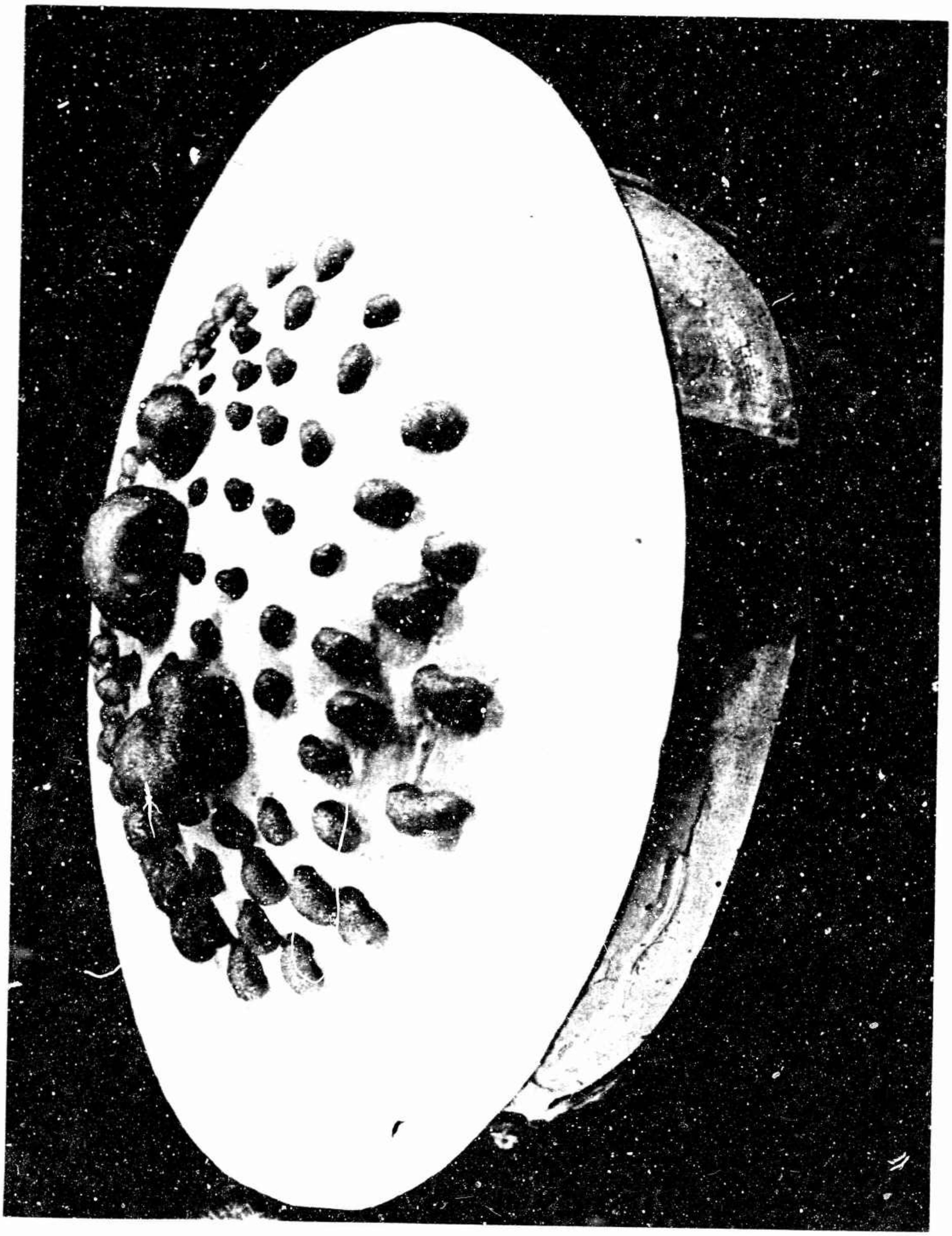

FIGURE 14. Expelling of Excess Foam Through Vent Holes

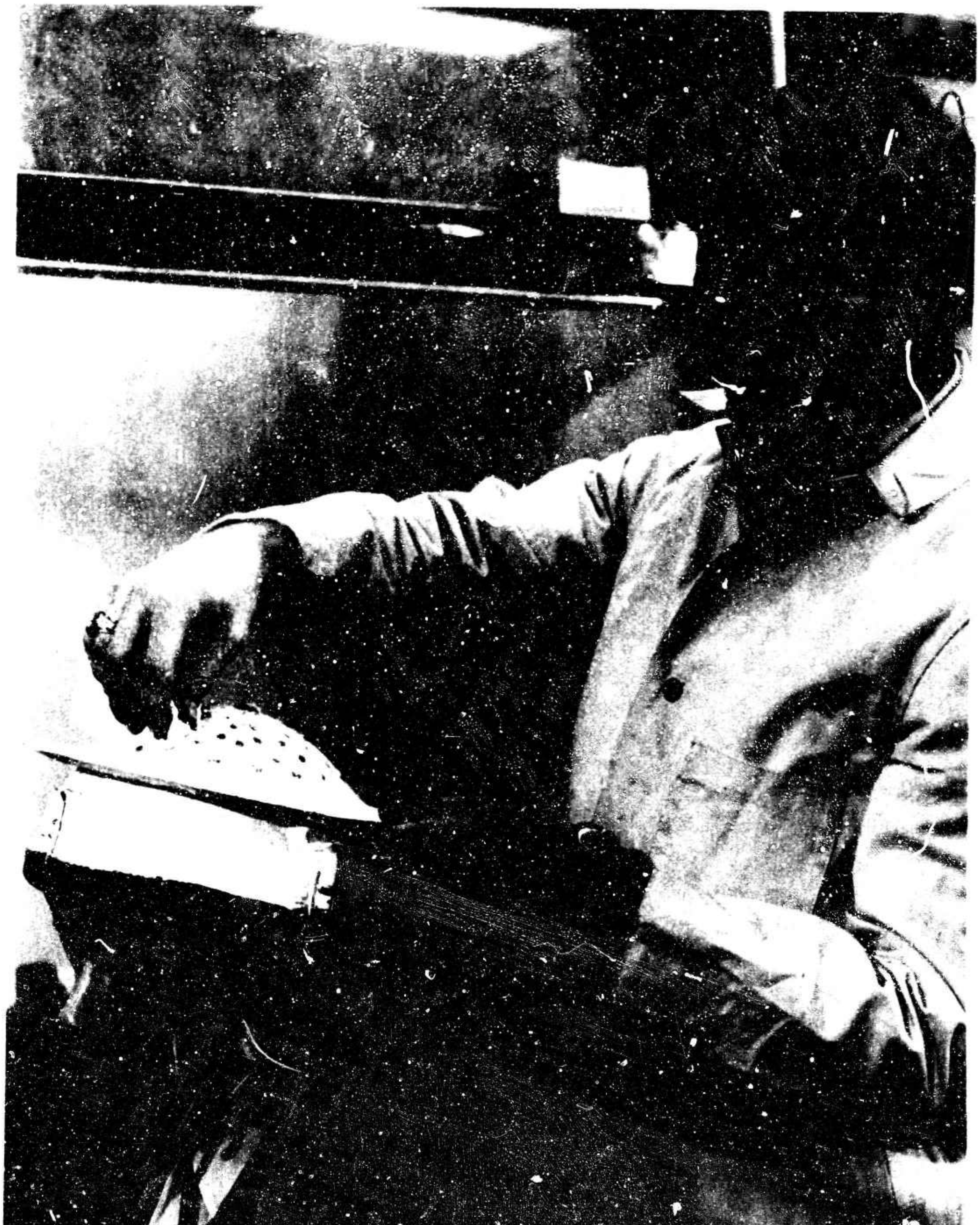

FIGURE 15. Wiping Away Excess Foam

FIGURE 16. Refitting Helmet Liner

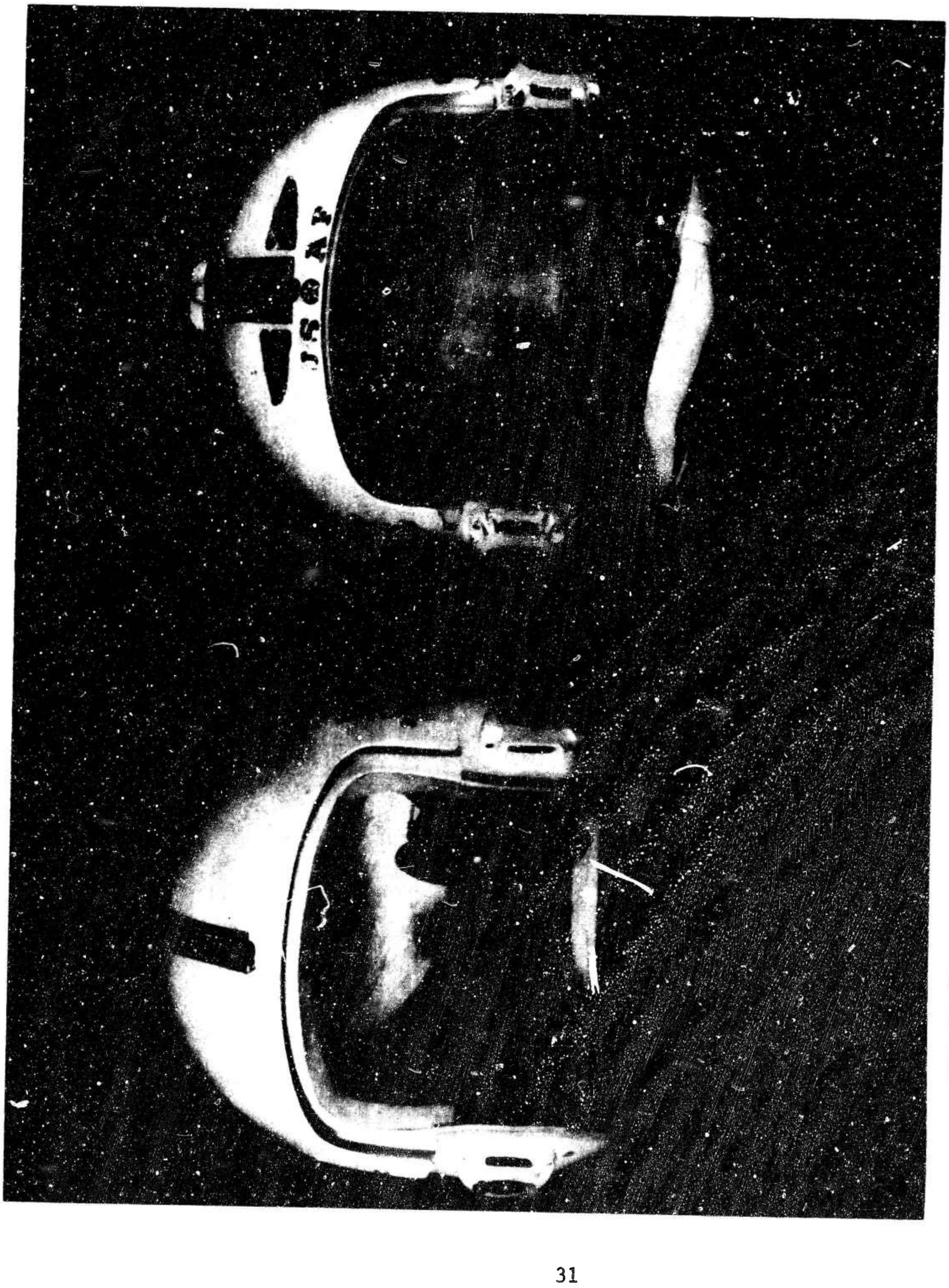

FIGURE 17. Detail of Padding Inside of Finished Helmet Liner (Right)

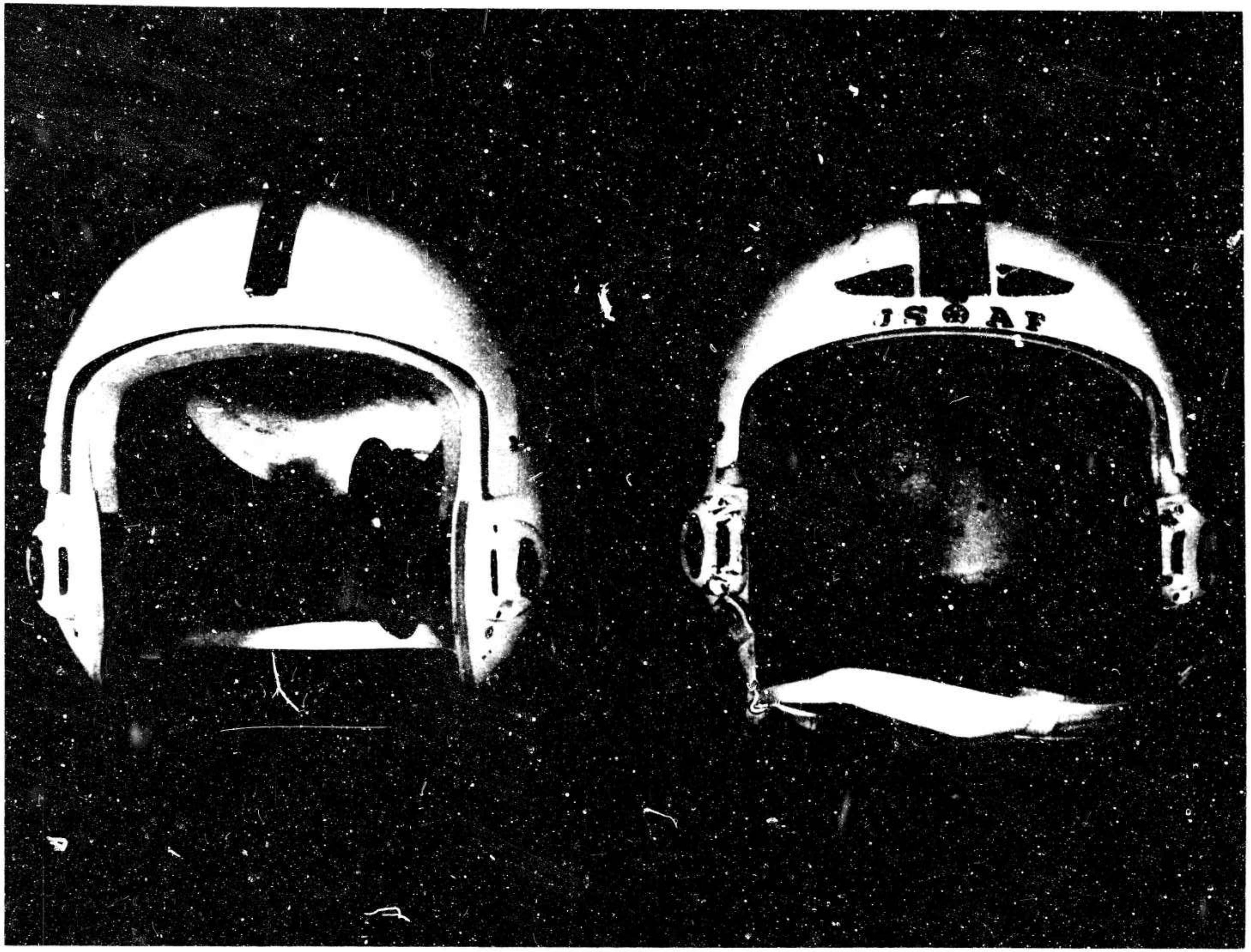

FIGURE 18. Standard Issue Helmet (Left) vs. Customized Helmet (Right)

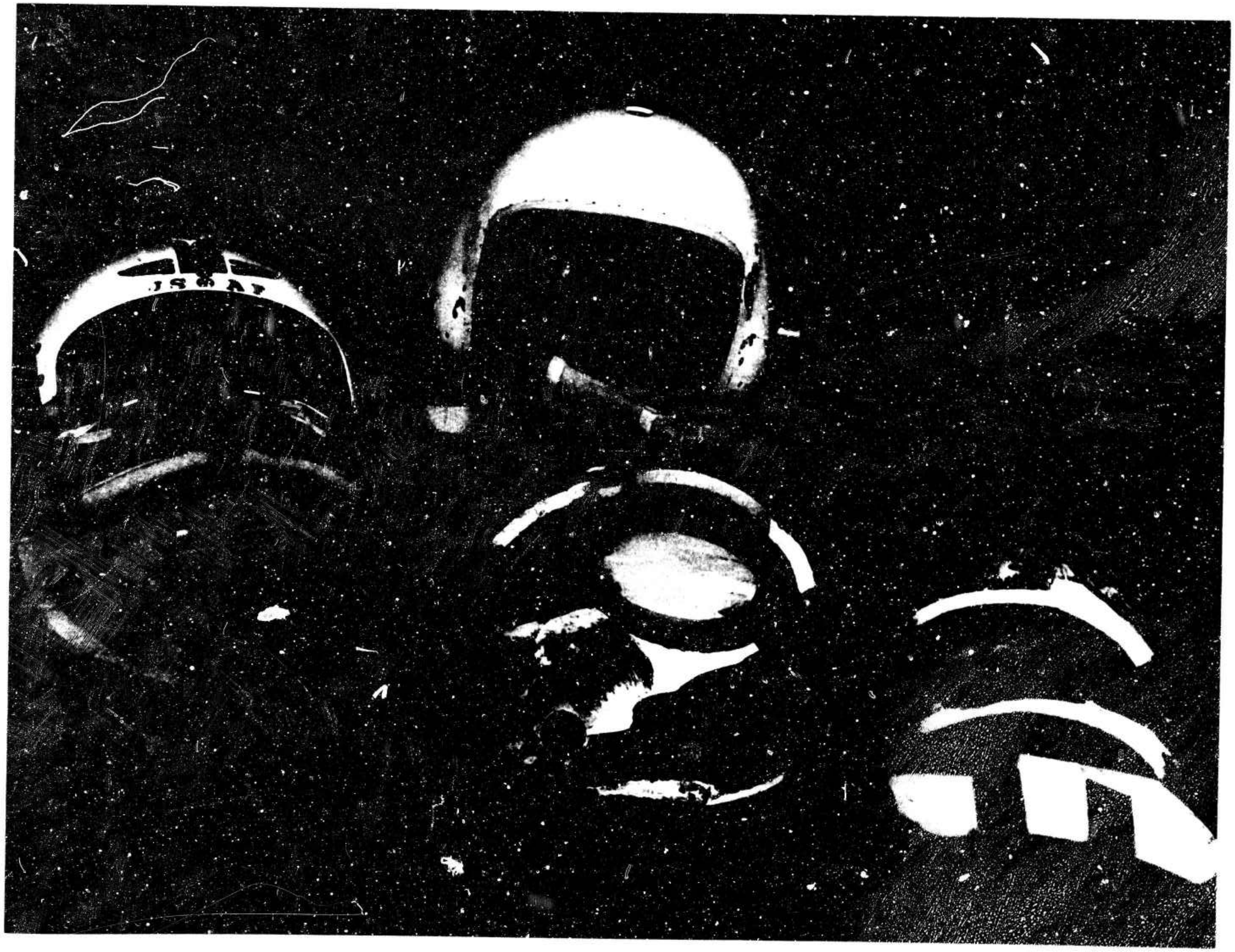

FIGURE 19. Standard Issue Helmet Disassembled

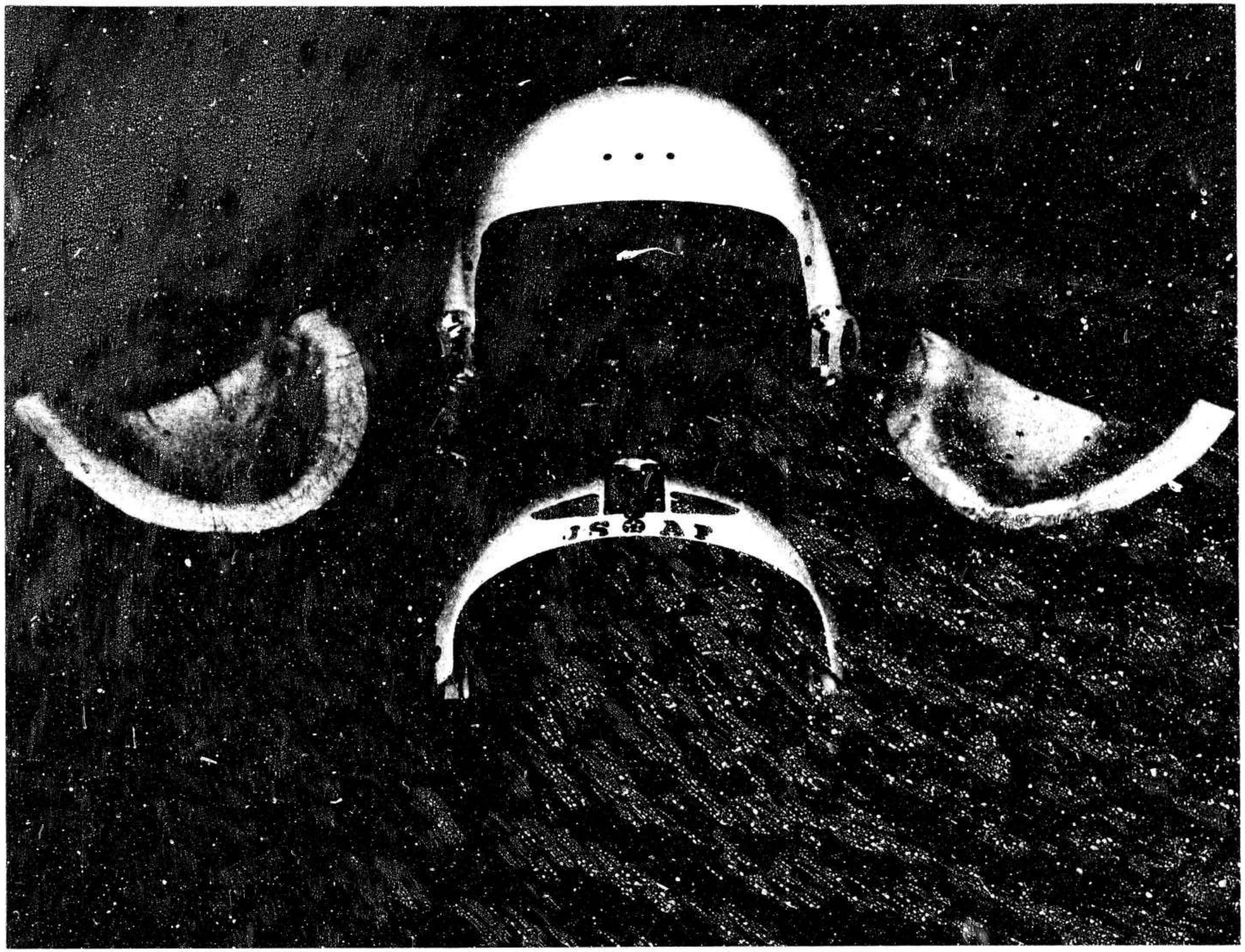

FIGURE 20. Customized Helmet Disassembled

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13. ABSTRACT

The feasibility of a foamed-in-place, form fitting foam helmet liner for Air Force crash or flying helmets ~~has been~~ proven. The work done under this program has demonstrated that high quality polyurethane foam helmet liners may be foamed-in-place directly on the flying crew member's head, producing a perfectly fitting helmet liner with a minimum of time, labor, and inconvenience. Furthermore, these liners may be produced at an extremely modest cost and a standard government issue helmet may be customized at a fraction of the cost of a commercially available customizing service and in a fraction of the time.

The work involved two areas of effort. One area centered around developing a suitable foam formulation to produce the foamed-in-place helmet liners. The other was concerned with fabricating a workable mold, which would be worn by the individual being fitted for a custom helmet liner during the foaming process.

A suitable polyurethane foam formulation ~~has been~~ tailored to the specific requirements for the foam-in-place helmet liners prepared under this program. Design and fabrication of a suitable mold in which the helmet liner is foamed has progressed to a point which has definitely demonstrated that the concept of foamed-in-place helmet liners is not only practical but also desirable.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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foam-in-place materials						
aircrew helmets						